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Predicting Cooling Garment Performance with CB Protective Clothing at Various Environmental Conditions

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The Science Behind the Warrior:

Yesterday, Today and

Performance of Liquid Circulating Cooling Garments: Background

- **Soldier Systems Often Include Microclimate Cooling Systems (MCS):**
  - Air Warrior (except Apache): Vapor compression MCS.
  - Air Warrior (Apache): Use existing Environmental Control System to chill a circulating liquid.
  - Cool The Force (HMMWV): Use add-on conditioned air to chill a circulating liquid (in testing).
  - Future Force Warrior: Exit criteria requires active MCS for Block II.

Performance of Liquid Circulating Cooling Garments: Problem & Need

- **No Simple Method Exists To Verify Performance Vs. Requirements:**
  - Physiological testing
    - Expensive (>$100K)
    - Long lead time (as much as 1 year or more).
  - Draft ASTM Thermal Manikin test method
    - Limited range (95°F ambient temperature only)
    - Requirements often include higher ambient temperatures (up to 125°F).
- **Alternate Approach Needed For Evaluation Of Liquid Circulating Cooling Garments:**
  - Less expensive (than physiological testing)
  - Shorter lead time (than physiological testing)
  - Applicable at higher temperatures (than Thermal Manikin testing)

Performance of Liquid Circulating Cooling Garments: Approach

- **Apply Standard Heat Transfer Principles To The Current Thermal Manikin Test Method As Follows:**
- **1. Conduct a standard Thermal Manikin test at 95°F.**
- **2. Apply standard heat transfer mathematics to calculate overall heat transfer coefficients.**
  - Separate coefficients must be calculated for “skin side” and environment side heat transfer.
  - Results in a system of 5 equations with 5 unknowns – solvable!
- **3. Use the heat transfer coefficients to estimate cooling garment performance at ambient temperatures other than 95°F.**
  - Equations also predict cooling performance for other design variables:
    - Fluid flow rate
    - Fluid temperature
    - Fluid composition
    - Skin temperature

Performance of Liquid Circulating Cooling Garments: Sample Results

- **Prototype Microclimate Cooling Garment**
  - "Shorty" cooling garment
- **Measure performance at two scenarios on a Thermal Manikin at 95 F**
  - Low fluid temp, high flow rate (high cooling rate)
  - High fluid temp, low flow rate (low cooling rate)
- **Predict performance at common scenario at 125 F**
  - Medium fluid temp and flow rate
  - Compare predicted results

Performance of Liquid Circulating Cooling Garments: Sample Results

Ambient temp 95 F	Test 1	Test 2
Fluid temp F	45.2	74.8
Flow rate gph	12.3	4.1
Actual cooling rate watts	491	135
Ambient temp 125 F	Predicted	Predicted
Fluid temp F	65	65
Flow rate gph	10	10
Actual cooling rate watts	271	251

- Predicted results vary by less than 8%

Performance of Liquid Circulating Cooling Garments: Conclusions

- **Prediction model has been developed to estimate the performance of microclimate cooling systems**
  - Less expensive and shorter lead time than physiological testing
  - Applicable to a wide range of ambient environments beyond the Thermal Manikin test
  - Allows parametric studies to evaluate affect of proposed design changes
- **Model permits evaluation of Microclimate Cooling Systems in comparison to Soldier System cooling requirements**